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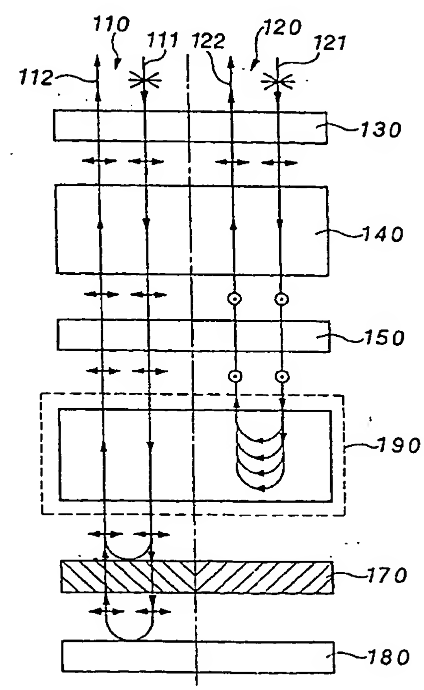
(54) Display device and electronic apparatus using the same

(57) A display device capable of obtaining a bright display is provided.

A polarizer 130 is arranged above an TN liquid crystal 140, and a light-scattering layer 150, a polarized light separator 160, a coloring layer 170, and a reflecting plate 180 are arranged under the TN liquid crystal 140. The polarized light separator 160 transmits a linearly polarized light component in a direction parallel to the page being incident from the upper side, reflects a linearly polarized light component in a direction perpendicular to the page, and can upwardly emit linearly polarized light parallel to the page in response to light being incident from the lower side. When voltage is not applied to liquid crystal 140, (120), light reflected by the polarized light separator 160 becomes white emission light 122. In a voltage applied condition (110), light transmitted through the polarized light separator 160 is colored by the coloring layer 170 to be color emission light 112

Fig. 4



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D scription

The present invention relates to a display device and such device incorporated in electronic apparatus.

Background Art

A conventional liquid crystal display device using a transmission polarized light axis changing means comprises a TN (Twisted Nematic) liquid crystal, an STN (Super-Twisted Nematic) liquid crystal, in a structure comprising successive layers of a first polarizer, the liquid crystal device, a color filter, a second polarizer and a reflecting plate. Such a device does not provide good efficiency of light use, and the display is generally dark, since background light is transmitted and then reflected right through the entire structure, which is a problem.

It is an object of the present invention to provide a display device, using a transmission polarized light axis changing means, which can provide a bright display.

Summary of the Invention

The present invention provides in a first aspect, a display device comprising:

transmission polarization changing means for selectively changing the polarisation axis of transmitted light in response to the application of voltage;

characterized by first and second polarized light separation means arranged on opposite sides of said transmission polarization changing means; and

optical means disposed on an opposite side of said second polarized light separation means relative to said transmission polarization changing means for emitting light, in a predetermined wavelength range, toward said second polarized light separation means in response to light from said second polarized light separation means,

wherein said first polarized light separation means is such as to transmit light linearly polarized in a first predetermined direction in response to light incident from a first side thereof, and to transmit from the first side light linearly polarized in the first predetermined direction in response to light incident form the second side, and

said second polarized light separation means is such as to transmit light linearly polarized in a second predetermined direction, being incident from said transmission polarization changing means and to transmit light incident form said optical means, and linearly polarized in the second predetermined direction to said transmission polarization changing means, and to reflect light linearly polarized in a third predetermined direction perpendicular to the second predetermined direction back to said transmission polarization changing means.

According to the present invention, there is provided a display device comprising:

transmission polarized light axis changing means which can change a transmission polarized light axis;

first and second polarized light separation means arranged on both the sides of the transmission polarized light changing means to interpose the transmission polarized light changing means; and

an optical element arranged on a side opposing the transmission polarized light axis changing means with respect to the second polarized light separation means the optical element being capable of emitting light of a predetermined wavelength area toward the second polarized light separation means in response to light from the second polarized light separation means,

characterised in that the first polarized light separation means is polarized light separation means which can emit linearly polarized light of a first predetermined direction, in response to light being incident from a first side of the first polarized light separation means, from a second side opposing the first side and can emit the linearly polarized light of the first predetermined direction from the first side in response to light being incident from the second side, and

the second polarized light separation means is polarized light separation means which transmits a linearly polarized light component of a second predetermined direction of light being incident from the transmission polarized light axis changing means to the optical element, reflects a linearly polarized light component of a third predetermined direction perpendicular to the second predetermined direction to the transmission polarized light axis changing means, and can emit linearly polarized light of the second predetermined direction to the transmission polarized light axis changing means in response to light being incident from the optical element.

In the display device of the present invention, depending on the state of the transmission polarized light axis of the transmission polarized light axis changing means, two display states, i.e., a first display state obtained by light reflected by the second polarized light separation means and a second display state obtained by light which is emitted from the optical element, is in a predetermined wavelength area, and is transmitted through the second polarized light separation means, can be obtained. Since the first display state is a display state obtained by light reflected by the second polarized light separation means, a bright display can be obtained.

Preferably, the second polarized light separation means is polarized light separation means which transmits, in response to light in an almost whole wavelength range of a visible light area, the linearly polarized light component of the second predetermined direction of the light being incident from the transmission polarized light axis changing means to the optical element, reflects the

linearly polarized light component of the third predetermined direction perpendicular to the second predetermined direction, and can emit the linearly polarized light of the second predetermined direction to the transmission polarized light axis changing means in response to light which is in the almost whole wavelength range of the visible light area and is incident from the optical element.

With the above arrangement, the first and second display states can be obtained in response to the light of the whole wavelength range of the visible light area, and transparent reflection or white reflection can be obtained in the first display state. In the second display state, a display of an arbitrary color can be obtained in the whole wavelength range of the visible light area depending on the optical element.

Preferably, the second polarized light separation means is polarized light separation means which transmits the linearly polarized light component of the second predetermined direction of the light being incident from the transmission polarized light axis changing means to the optical element as linearly polarized light of the second predetermined direction.

Preferably, the second polarized light separation means is a multilayered structure obtained by stacking a plurality of layers, and the multilayered structure has the plurality of layers in which adjacent layers have refractive indexes which are equal to each other in the second predetermined direction and are different from each other in the third direction.

As the transmission polarized light axis changing means, a liquid-crystal element is preferably used, and a TN liquid-crystal element, an STN liquid-crystal element, or an ECB liquid-crystal element is especially preferably used. The STN liquid-crystal element also includes an STN liquid-crystal element using a color-correction optical anisotropic material.

Preferably, the first polarized light separation means is a polarizer.

Preferably, the optical element is an optical element which absorbs light in a wavelength area other than the predetermined wavelength area of the light from the second polarized light separation means, can reflect the light in the predetermined wavelength area toward the second polarized light separation means, and can transmit the light in the predetermined wavelength area.

As the optical element, an optical element which can emit light in the predetermined wavelength area in response to the light from the second polarized light separation means may be used.

As the optical element, a hologram which can color the light in the predetermined wavelength area by the light from the second polarized light separation means can also be used.

Preferably, reflecting means arranged on a side opposing the second polarized light separation means with respect to the optical element is further arranged, and, as the reflection means, the reflection means which can reflect at least the light in the predetermined wavelength area toward the optical element is used. In this manner, the second display state by light from the optical means can be made bright.

Preferably, a second optical element arranged on a side opposing the transmission polarized light axis changing means with respect to the second polarized light separation means is further comprised, the second optical element can emit light in a second predetermined wavelength area different from the first predetermined wavelength area toward the second polarized light separation means in response to light from the second polarized light separation means and is arranged at a position different from that of the optical element and a display by at least light in the first predetermined wavelength area and light in the second predetermined wavelength area on the same screen is made possible. In this manner, in addition to a display of a first color by light from the optical element, a display of a second color different from the first color can be obtained. As a result, a display of at least two colors can be obtained.

In this case, preferably, the second optical element is an optical element which absorbs light in a wavelength area other than the second predetermined wavelength area of the light from the second polarized light separation means, can reflect the light in the second predetermined wavelength area toward the second polarized light separation means, and can transmit the light in the second predetermined wavelength area.

As the second optical element, an optical element which can emit light in the second predetermined wavelength area in response to the light from the second polarized light separation means may be used.

As the second optical element, a hologram which can color the light in the second predetermined wavelength area by the light from the second polarized light separation means is preferably used.

Preferably, second reflecting means arranged on a side opposing the second polarized light separation means with respect to the second optical element is further comprised, and, as the second reflection means, reflection means which can reflect at least the light in the second predetermined wavelength area toward the second optical element is used. In this manner, the second display state by light from the second optical means can be made bright.

Preferably, at least one of the optical element and the second optical element is a color filter.

At least one of the optical element and the second optical element may be a phosphor.

Preferably, a third optical element arranged on a side opposing the transmission polarized light axis changing means with respect to the second polarized light separation means is further comprised, the third optical element absorbs light in an almost whole wavelength range of a visible light area. In this manner, in addition to a display of a first color by light from the optical element, a black display by the third optical element

can be obtained.

Preferably, first and second transparent substrates arranged both the sides of the transmission polarized light axis changing means to sandwich the transmission polarized light axis changing means are further comprised, the first polarized light separation means is arranged on a side opposing the transmission polarized light axis changing means with respect to the first transparent substrate, and the second polarized light separation means is arranged on a side opposing the transmission polarized light axis changing means with respect to the second transparent substrate.

In this case, preferably, as the first and second transparent substrates, glass substrates are used.

When the glass substrate is used as the second transparent substrate as described above, a so-called parallax error in which a double display is caused by the thickness of the glass substrate easily occurs. In this case, when a polychromatic display is performed in units of rows or characters in an icon portion or dots, a display in which a parallax error is negligible can be obtained.

As the second transparent substrate, a plastic film substrate can also be used.

Preferably, light-scattering means is further comprised. In this manner, the first display state by light reflected by the second polarized light separation means is made white.

In the display device of the present invention, an active element such as a TFT or an MIM may be arranged.

Brief Description of the drawings

Preferred embodiments of the invention will now be described merely by way of example with reference to the accompanying drawings, in which:

Figures 1 and 2 are schematic side views of a first embodiment of the invention;
Figures 3 and 4 are schematic side views of a second embodiment of the invention;
Figure 5 is a view for explaining a liquid-crystal display device according to a third embodiment of the present invention, in which Fig. 5A is a plan view, Fig. 5B is an exploded sectional view, and Fig. 5C is a partially enlarged sectional view of an A portion in Fig. 5B;
Figures 6 to 8 are sketches illustrating a means of reducing parallox error in Figure 5;
Fig. 9 is a view for explaining a liquid-crystal display device according to a fourth embodiment of the present invention, in which Fig. 9A is a plan view, and Fig. 9B is an exploded sectional view.
Fig. 10 is a view for explaining a liquid-crystal display device according to a fifth embodiment of the present invention, in which Fig. 10A is a plan view, and Fig. 10B is an exploded sectional view.
Fig. 11 is a view for explaining a liquid-crystal display device according to a sixth embodiment of the present invention, in which Fig. 11A is a plan view, and Fig. 11B is an xploded sectional view.
Fig. 12 is a view for explaining a liquid-crystal display device according to a seventh embodiment of the present invention, in which Fig. 12A is a plan view, and Fig. 12 is an exploded sectional view.
Fig. 13 is a view for explaining a liquid-crystal display device according to an eighth embodiment of the present invention, in which Fig. 13A is a plan view, and Fig. 13B is an exploded sectional view.
Figs. 14 and 15 are plan views for explaining the liquid-crystal display device according to the eighth embodiment.
Fig. 16 is a view for explaining a liquid-crystal display device according to a ninth embodiment of the present invention, in which Fig. 16A is a plan view, Fig. 16B is an exploded sectional view, and Fig. 16C is a partially enlarged plan view.
Fig. 17 shows an example of a portable telephone set in which a display device according to the present invention is arranged.

Description of the Preferred Embodiments

Referring to Fig. 1, in this liquid-crystal display device, a TN liquid crystal 140 is used as a transmission polarized light axis changing element. A polarizer 130 is arranged above the TN liquid crystal 140. The polarizer 130 transmits linearly polarized light of a predetermined first direction of incident light (parallel to the page), and absorbs linearly polarized light of a direction perpendicular to the linearly polarized light of the first direction. A light scattering layer 150, a polarized light separator 160, a coloring layer 170, and a reflecting plate 180 are arranged in this order under the TN liquid crystal 140. The following description is performed on the assumption that the left side of the liquid-crystal display device serves as a voltage applied portion 110 in which voltages are applied to electrodes in liquid crystal 140 and the right side serves as a voltage non-applied portion 120.

The polarized light separator 160 comprises a (1/4) λ plate 162 and a cholesteric liquid-crystal layer 164. The cholesteric liquid crystal reflects a circularly polarized light which has a wavelength equal to the pitch of the liquid crystal and has the same rotating direction as that of the liquid crystal, and transmits other light. Therefore, for example, when a left-rotational cholesteric liquid crystal having a pitch of 5,000Å is used as the cholesteric liquid-crystal layer 164, an element which reflects left-circularly polarized light having a wavelength of 5,000Å and transmits right-circularly polarized light or other wavelength left-circularly polarized light can be obtained. In addition, when left-rotational cholesteric liquid crystal is used, and its pitch is changed within the cholesteric liquid crystal over the whole wavelength range of visible light, an element which reflects left-cir-

cularly polarized light over not only a single color but also whole white light and transmits right-circularly polarized light can be obtained.

In the polarized light separator 160 obtained by combining the cholesteric liquid-crystal layer 164 and the (1/4) λ plate 162 described above, when linearly polarized light of a predetermined third direction (perpendicular to the page) is incident from the (1/4) λ plate 162, the linearly polarized light is changed by the (1/4) λ plate 162 into left-circularly polarized light, reflected by the cholesteric liquid-crystal layer 164 and emitted again as linearly polarized light of the predetermined third direction by the (1/4) λ plate 162. When linearly polarized light of a second direction (parallel to the page) perpendicular to the third direction is incident, the linearly polarized light is changed by the (1/4)λ plate 162 into right-circularly polarized light and transmitted through the cholesteric liquid-crystal layer 164. In response to light being incident from the lower side of the cholesteric liquid-crystal layer 164, linearly polarized light of the second direction is emitted above the (1/4) λ plate 162.

In this manner, the polarized light separator 160 obtained by combining the cholesteric liquid-crystal layer 164 and the (1/4) λ plate 162 is a polarized light separation means which transmits a linearly polarized light component of the predetermined second direction of light being incident from the (1/4) λ plate 162, reflects a linearly polarized light component of the third direction perpendicular to the predetermined second direction, can emit linearly polarized light of the second direction to the (1/4) λ plate 162 in response to light being incident from the cholesteric liquid-crystal layer 164. As a polarized light separation means having this function, in addition to the polarized light separator 160 obtained by combining the cholesteric liquid-crystal layer 164 and the (1/4) λ plate 162 described above, a means using a film obtained by stacking a large number of films (U.S. P. 4,974,219), a means for separating reflection polarized light from transmission polarized light by using an angle of polarization (SID 92 DIGEST pp. 427 to 429), and a means using a hologram are known.

Referring to Fig. 1 again, in the voltage non-applied portion 120 on the right, natural light 121 is changed by the polarizer 130 into linearly polarized light of a direction parallel to the drawing surface. Thereafter, the light is twisted at 90° in polarization direction by the TN liquid crystal 140 to be linearly polarized light of a direction perpendicular to the drawing surface, the linearly polarized light is changed by the (1/4) λ plate 162 into left-circularly polarized light, and the left circularly polarized light is reflected by the cholesteric liquid-crystal layer 164 to be incident on the (1/4) λ plate 162 again. The left-circularly polarized light is changed by the (1/4) λ plate 162 into linearly polarized light of a direction perpendicular to the drawing surface, and the linearly polarized light is twisted in polarization direction by the TN liquid crystal 140 to be linearly polarized light of a direction parallel to the drawing surface. The linearly polarized light is emitted from the polarizer 130 as linearly polarized light of a direction parallel to the drawing surface. In this manner, in a voltage non-applied state, since incident light is not absorbed by the polarized light separator 160 but reflected by the polarized light separator 160, a bright display can be obtained. Since the light-scattering layer 150 is formed between the (1/4) λ plate 162 and the TN liquid crystal 140, the state of the reflected light from the polarized light separator 160 is changed from a specular state to a white state.

In the voltage applied portion 110 on the left, natural light 111 is changed by the polarizer 130 into linearly polarized light of a direction parallel to the drawing surface. Thereafter, the linearly polarized light is transmitted through the TN liquid crystal 140 without changing the polarization direction and changed by the (1/4) λ plate 162 into right-circularly polarized light, and the right-circularly polarized light is transmitted through the cholesteric liquid-crystal layer 164. The right-circularly polarized light transmitted through the cholesteric liquid-crystal layer 164 is partially reflected by the coloring layer 170, incident on the (1/4) λ plate 162 again, and changed by the (1/4) λ plate 162 into linearly polarized light of a direction parallel to the drawing surface. The linearly polarized light is transmitted through the TN liquid crystal 140 without changing the polarization direction and emitted from the polarizer 130 as linearly polarized light of the direction parallel to the drawing surface. The right-circularly polarized light transmitted through the cholesteric liquid-crystal layer 164 is partially transmitted through the coloring layer 170 while being absorbed by the coloring layer 170, and is reflected by the reflecting plate 180. Thereafter, the reflected light is transmitted through the coloring layer 170 while being absorbed by the coloring layer 170, is reflected by the cholesteric liquid-crystal layer 164, and is transmitted through the coloring layer 170 while being absorbed by the coloring layer 170. The transmitted light is reflected by the reflecting plate 180 again, is transmitted through the coloring layer 170 while being absorbed by the coloring layer 170, and is incident on the (1/4) λ plate 162 through the cholesteric liquid crystal layer 164. The incident light is changed by the (1/4) λ plate 162 into linearly polarized light of a direction parallel to the drawing surface. The linearly polarized light is transmitted through the TN liquid crystal 140 without changing the polarization direction and emitted from the polarizer 130 as linearly polarized light of the direction parallel to the drawing surface.

As described above, in the voltage non-applied portion 120, light reflected by the polarized light separator 160 is scattered by the light-scattering layer 150 to be white emission light 122. In the voltage applied portion 110, light transmitted through the polarized light separator 160 is colored by the coloring layer 170 to be color emission light 112. Therefore, a color display can be obtained on a white background. Since all the wavelengths of a visible light area are absorbed by using black in the

coloring layer 170, a black display is obtained on a white background. Since the reflecting plate 180 is provided, the color emission light 112 colored by the coloring layer 170 becomes bright.

Referring to Fig. 2, the polarized light separator 160 comprises the (1/4) λ plate 162, the cholesteric liquid crystal layer 164, and a (1/4) λ plate 166.

In the polarized light separator 160 in which the (1/4) λ plates 162 and 166 are arranged on both the sides of the cholesteric liquid-crystal layer 164, when linearly polarized light of a predetermined first direction is incident from the (1/4) λ plate 162, the linearly polarized light is changed by the (1/4) λ plate 162 into left-circularly polarized light. The left-circularly polarized light is reflected by the cholesteric liquid-crystal layer 164 and changed by the (1/4) λ plate 162 into linearly polarized light of a predetermined third direction, and the linearly polarized light is emitted. When linearly polarized light of a second direction perpendicular to the first direction is incident, the linearly polarized light is changed by the (1/4) λ plate 162 into right-circularly polarized light, the right-circularly polarized light is transmitted through the cholesteric liquid-crystal layer 164 and changed by the (1/4) λ plate 162 into the linearly polarized light of the second direction again, and the linearly polarized light is emitted. In response to light being incident from the lower side of the (1/4) λ plate 166, linearly polarized light of the second direction is emitted above the (1/4) λ plate 162.

As described above, the polarized light separator 160 obtained by combining the cholesteric liquid-crystal layer 164 and the (1/4) λ plates 162 and 166 is a polarized light separation means which transmits a linearly polarized light component of the predetermined second direction of light being incident from the (1/4) λ plate 162 as linearly polarized light of the second direction, reflects a linearly polarized light component of a third direction perpendicular to the predetermined second direction, and, in response to light being incident from the (1/4) λ plate 166, can emit the linearly polarized light of the second direction to the (1/4) λ plate 162. As a polarized light separation means having this function, in addition to the polarized light separator 160 obtained by combining the cholesteric liquid-crystal layer 164 and the (1/4) λ plates 162 and 166 described above, a means using a film obtained by stacking a large number of films (U.S.P. 4,974,219), a means for separating reflection polarized light from transmission polarized light by using an angle of polarization (SID 92 DIGEST pp. 427 to 429), a means using a hologram, and a polarized light separator in which layers having different refractive indexes in a specific direction (to be described later) are alternately stacked are known.

Referring to Fig. 2 again, the operation of the voltage non-applied portion 120 on the right is the same as that of the voltage non-applied portion 120 on the light in Fig. 1. More specifically, the natural light 121 is changed by the polarizer 130 into linearly polarized light of a direction parallel to the drawing surface. Thereafter, the linearly polarized light is twisted in polarization direction by the TN liquid crystal 140 to be linearly polarized light of a direction perpendicular to the drawing surface, and the linearly polarized light is changed by the (1/4) λ plate 162 into left-circularly polarized light. The left-circularly polarized light is reflected by the cholesteric liquid-crystal layer 164, incident on the (1/4) λ plate 162, and changed by the (1/4) λ plate 162 into linearly polarized light of a direction perpendicular to the drawing surface. The linearly polarized light is twisted in polarization direction by the TN liquid crystal 140 to be linearly polarized light of a direction parallel to the drawing surface, and the linearly polarized light is emitted from the polarizer 130 as linearly polarized light of the direction parallel to the drawing surface. In this manner, in a voltage non-applied state, since light is not absorbed by the polarized light separator 160 but reflected by the polarized light separator 160, a bright display can be obtained. Since the light-scattering layer 150 is arranged between the (1/4) λ plate 162 and the TN liquid crystal 140, the state of the reflected light from the polarized light separator 160 is changed from a specular state to a white state.

In the voltage applied portion 110 on the left, natural light 111 is changed by the polarizer 130 into linearly polarized light of a direction parallel to the drawing surface. 'Thereafter, the linearly polarized light is transmitted through the TN liquid crystal 140 without changing the polarization direction and changed by the (1/4) λ plate 162 into right-circularly polarized light, and the right-circularly polarized light is transmitted through the cholesteric liquid-crystal layer 164. The right-circularly polarized light transmitted through the cholesteric liquid-crystal layer 164 is changed by the (1/4) λ plate 166 into linearly polarized light of a direction parallel to the drawing surface The linearly polarized light is partially reflected by the coloring layer 170, transmitted through the (1/4) λ plate 166, the cholesteric liquid-crystal layer 164, and the (1/4) λ plate 162 again, transmitted through the TN liquid crystal 140 as linearly polarized light of the direction parallel to the drawing surface without changing the polarization direction, and emitted from the polarizer 130 as the linearly polarized light of the direction parallel to the drawing surface. The linearly polarized light emitted from the (1/4) λ plate 166 is partially transmitted through the coloring layer 170 while being absorbed by the coloring layer 170 and reflected by the reflecting plate 180. Thereafter, the reflected light is transmitted through the coloring layer 170 while being absorbed by the coloring layer 170, transmitted through the (1/4) λ plate 166, the cholesteric liquid-crystal layer 164, and the (1/4) λ plate 162 again, transmitted through the TN liquid crystal 140 as the linearly polarized light of the direction parallel to the drawing surface without changing the polarization direction, and emitted from the polarizer 130 as the linearly polarized light of the direction parallel to the drawing surface.

As described above, in the voltage non-applied portion 120, light reflected by the polarized light separator 160 is scattered by the light-scattering layer 150 to be white emission light 122. In the voltage applied portion 110, light transmitted through the polarized light separator 160 is colored by the coloring layer 170 to be color emission light 112. Therefore, a color display can be obtained on a white background. Since all the wavelengths of a visible light area are absorbed by using black in the coloring layer 170, a black display is obtained on a white background. Since the reflecting plate 180 is arranged, the color emission light 112 colored by the coloring layer 170 becomes bright.

In the above description, the TN liquid crystal 140 is used as an example. However, even if a liquid crystal such as an STN liquid crystal or an ECB (Electrically Controlled Birefringence) liquid crystal in which other transmission polarized light axes can be changed by a voltage or the like is used in place of the TN liquid crystal 140, the same basic operation principle can be used.

The principle of the present invention in a second embodiment of polarized light separator will be described below with reference to Figs. 3 and 4.

Referring to Fig. 4, in this liquid-crystal display device, the TN liquid crystal 140 is used as a transmission polarized light axis changing element. A polarizer 130 is arranged above the TN liquid crystal 140. The light scattering layer 150, a polarized light separator 190, a coloring layer 170, and a reflecting plate 180 are arranged in this order under the TN liquid crystal 140. The following description is performed on the assumption that the left side of the liquid-crystal display device serves as the voltage applied portion 110 and the right side serves as the voltage non-applied portion 120.

The polarized light separator 190 has a structure in which two different layers 191 (A layer) and 192 (B layer) are alternately stacked as shown in Fig. 3. In the A layer 191, a refractive index (n_{AX}) of an X-axis direction (first direction) is different from a refractive index (n_{AY}) of a Y-axis direction. In the B layer 192, a refractive index (n_{BX}) of the X-axis direction) is equal to a refractive index (n_{BY}) of the Y-axis direction. The refractive index (n_{AY}) of the Y-axis direction in the A layer 191 is equal to the refractive index (n_{BY}) of the Y-axis direction in the B layer 192.

Therefore, linearly polarized light of the Y-axis direction of light being incident on the polarized light separator 190 is transmitted through the polarized light separator to be emitted as linearly polarized light of the Y-axis direction.

On the other hand, assume that the thickness of the A layer 191 in a Z-axis direction is represented by t_A, that the thickness of a B layer 52 is represented by t_B, and that the wavelength of incident light is represented by λ,

$$t_A \cdot n_{AX} + t_B \cdot n_{BX} = \lambda/2 \qquad (1)$$

is established. In this state, of light which has the wavelength λ and is incident on the polarized light separator 190, linearly polarized light of the X-axis direction is reflected by the polarized light separator 190 as the linearly polarized light of the X-axis direction.

The thickness t_A of the A layer 191 in the Z-axis direction and the thickness t_B of the B layer 192 in the Z-axis direction are variously changed to establish the equation (1) described above over the whole visible wavelength range. In this manner, a polarized light separator which reflects the linearly polarized light of the linearly polarized light of the X-axis direction as the linearly polarized light of the X-axis direction over not only a single color but also whole white light and transmits right-circularly polarized light and transmits light of the Y-axis direction as linearly polarized light of the Y-axis direction can be obtained.

The polarized light separator as described above is disclosed as a reflective polarizer in International Unexamined Publication (WO95/17692).

As described above, in the polarized light separator 190 in which layers having different refractive indexes in the predetermined third direction (X-axis direction) are alternately stacked, when linearly polarized light of the predetermined third direction is incident from the TN liquid crystal 140, the light is reflected by the polarized light separator 190 and directly emitted as the linearly polarized of the predetermined third direction. When linearly polarized light of the second direction (Y-axis direction) perpendicular to the third direction is incident, the light is transmitted through the polarized light separator 190 and directly emitted as second linearly polarized light. In response to light being incident from the reflecting plate 180, linearly polarized light of the second direction is emitted to the TN liquid crystal 140.

Referring to Fig. 4, natural light 121 is changed by the polarizer 130 into linearly polarized light of a direction parallel to the drawing surface. Thereafter, the light is twisted at 90° in polarization direction by the TN liquid crystal 140 to be linearly polarized light of a direction perpendicular to the drawing surface, and the linearly polarized light is reflected by the polarized light separator 190. The linearly polarized light of the direction perpendicular to the drawing surface is directly twisted at 90° in polarization direction by the TN liquid crystal 140 to be linearly polarized light of the direction parallel to the drawing surface, and the linearly polarized light is emitted from the polarizer 130 as the linearly polarized light of the direction parallel to the drawing surface. In this manner, in a voltage non-applied state, since incident light is not absorbed by the polarized light separator 190 but reflected by the polarized light separator 190, a bright display can be obtained. Since the light-scattering layer 150 is formed between the polarized light separa-

tor 190 and the TN liquid crystal 140, the state of the reflected light from the polarized light separator 190 is changed from a specular state to a white state.

In the voltage applied portion 110 on the left, natural light 111 is changed by the polarizer 130 into linearly polarized light of a direction parallel to the drawing surface. Thereafter, the linearly polarized light is transmitted through the TN liquid crystal 140 and the polarized light separator 190 without changing the polarization direction. The linearly polarized light is partially reflected by the coloring layer 170, transmitted through the polarized light separator 190 again, transmitted through the TN liquid crystal 140 as the linearly polarized light of the direction parallel to the drawing surface without changing the polarization direction, and emitted from the polarizer 130 as linearly polarized light of a direction parallel to the drawing surface. The linearly polarized light emitted from the polarized light separator 190 is partially transmitted through the coloring layer 170 while being absorbed by the coloring layer 170, and is reflected by the reflecting plate 180. Thereafter, the light is transmitted through the coloring layer 170 while being absorbed by the coloring layer 170 again, transmitted through the polarized light separator 190 again, transmitted through the TN liquid crystal 140 as the linearly polarized light of the direction parallel to the drawing surface without changing the polarization direction, and emitted from the polarizer 130 as the linearly polarized light of the direction parallel to the drawing surface.

As described above, in the voltage non-applied portion 120, light reflected by the polarized light separator 190 is scattered by the light-scattering layer 150 to be white emission light 122. In the voltage applied portion 110, light transmitted through the polarized light separator 190 is colored by the coloring layer 170 to be color emission light 112. Therefore, a color display can be obtained on a white background. Since all the wavelengths of a visible light area are absorbed by using black in the coloring layer 170, a black display is obtained on a white background. Since the reflecting plate 180 is arranged, the color emission light 112 colored by the coloring layer 170 becomes bright.

In the above description, the TN liquid crystal 140 is used as an example. However, even if a liquid crystal such as an STN liquid crystal or an ECB (Electrically Controlled Birefringence) liquid crystal in which other transmission polarized light axes can be changed by a voltage or the like is used in place of the TN liquid crystal 140, the same basic operation principle can be used.

Referring to Figure 5, in a liquid-crystal display device 10 according to this embodiment, an STN cell 20 is used as a transmission polarized light axis changing optical element. A phase difference film 14 and a polarizer 12 are arranged above the STN cell 20 in this order. A diffusion plate 30, a polarized light separator 40, a color filter 60, and a reflecting plate 50 are arranged under the STN cell 20 in this order. The color filter 60 is arranged on the reflecting plate 50 by printing. In the STN cell 20, an STN liquid crystal 26 is sealed in a cell constituted by two glass substrates 21 and 22 and the sealing member 23. A transparent electrode 24 is arranged on the lower surface of the glass substrate 21, and a transparent electrode 25 is arranged on the upper surface of the glass substrate 22. As the material of the transparent electrodes 24 and 25, ITO (Indium Tin Oxide), tin oxide or the like can be used. The phase-difference film 14 is used as a color-correction optical anisotropic material to correct a color generated by the STN cell 20.

As shown in Fig. 5C, the reflecting plate 50 is manufactured by forming a deposition film 54 consisting of aluminium, silver, or the like on a substrate 52. As the substrate 52, a glass substrate, a PET (polyethylene terephthalate) substrate, a PC (polycarbonate) substrate, or the like is used. When the PET substrate is used as the substrate 52, the deposition film 54 consisting of aluminium or silver may be formed on the PET substrate after the surface of the PET substrate is coarsened.

As shown in Fig. 5A, the liquid-crystal display device 10 according to this embodiment comprises two display areas, i.e., a dot portion 210 and an icon portion 240.

The dot portion 210 comprises dot row display portions 220 and 230 constituting two rows. In correspondence with the dot row display portions 220 and 230, color filters 620 and 630 are arranged on the reflecting plate 50. As shown in Fig. 7, the dot row display portion 220 is constituted by dot display portions 221 to 224, and the dot row display portion 230 is constituted by dot display portions 231 to 234. One character or one symbol is displayed on each of the dot display portions 221 to 224 and the dot display portions 231 to 234.

The icon portion 240, as shown in Fig. 6, comprises three icons 241 to 243. In correspondence with the icons 241 to 243, color filters 641 to 643 are arranged on the reflecting plate 50.

As the polarized light separator 40 according to this embodiment, a polarized light separator described by using Figs. 2 and 4, i.e., a polarized light separator which transmits a linearly polarized light component of a predetermined second direction of light being incident from the STN cell 20 as linearly polarized light of the second direction, reflects a linearly polarized light component of a third direction perpendicular to the predetermined second direction and can emit the linearly polarized light of the second direction to the STN cell 20 in response to light being incident from the reflecting plate 50 is used.

As a polarized light separator having the above function, a polarized light separator obtained by interposing a cholesteric liquid-crystal layer between two (1/4) λ plates, a polarized light separator using a film obtained by stacking a plurality of layers, a polarized light separator which uses an angle of polarization to separate reflected polarized light from transmission polarized light and a polarized light separator using a holo-

gram. In this embodiment, the polarized light separator 190 described by using Fig. 3, i.e., the polarized light separator disclosed as a reflective polarizer in International Unexamined Publication (WO95/17692), is used.

As the polarized light separator 40 according to this embodiment, a polarized light separator described by using Fig. 1, i.e., a polarized light separator which transmits a linearly polarized light component of a predetermined second direction of light being incident from the STN cell 20, reflects a linearly polarized light component of a third direction perpendicular to the predetermined second direction, and can emit the linearly polarized light of the second direction to the STN cell 20 in response to light being incident from the reflecting plate 50 can also be used.

In operation of the liquid-crystal display device 10, in a voltage non-applied area, natural light is changed by the polarizer 12 into linearly polarized light of a predetermined direction. Thereafter, the light is twisted at a predetermined angle in polarization direction by the STN cell 20 to be linearly polarized light, the linearly polarized light is not absorbed by the polarized light separator 40 but reflected by the polarized light separator 40 and twisted at a predetermined angle in polarization direction by the STN cell 20, and the light is emitted from the polarizer 12 as linearly polarized light. In this manner, in a voltage non-applied state, since incident light is not absorbed by the polarized light separator 40 but reflected by the polarized light separator 40, a bright display can be obtained. Since the diffusion plate 30 is formed between the STN cell 20 and the polarized light separator 40, the state of the reflected light from the polarized light separator 40 is changed from a specular state to a white state.

In the voltage applied area, natural light is changed by the polarizer 12 into linearly polarized light of a predetermined direction. Thereafter, the linearly polarized light is transmitted through the STN cell 20 and the diffusion plate 30 as linearly polarized light and also transmitted through the polarized light separator 40 as linearly polarized light. The transmitted linearly polarized light is partially colored and reflected by the color filter 60, transmitted through the polarized light separator 40, the diffusion plate 30, the STN cell 20, and the polarizer 12, and emitted as linearly polarized light. The other part of the linearly polarized light transmitted through the polarized light separator 40 is transmitted through the color filter 60 as linearly polarized light while being absorbed by the color filter 60, and is reflected by the reflecting plate 50. Thereafter, the reflected light is transmitted through the color filter 60 again while being absorbed by the color filter 60, transmitted through the polarized light separator 40, the diffusion plate 30, the STN cell 20, and the polarizer 12, and emitted as linearly polarized light.

As described above, in the voltage non-applied area, light reflected by the polarized light separator 40 is scattered by the diffusion plate 30 to be emitted as linearly polarized light. In the voltage applied area, light transmitted through the polarized light separator 40 is colored by the color filter 60 to be color linearly polarized light. Therefore, a color display can be obtained on a white background. Since all the wavelengths of a visible light area are absorbed by using black in a part of the color filter, a black display is partially obtained. Since the reflecting plate 50 is arranged, a color display by th color filter 60 becomes bright.

In the liquid-crystal display device 10 according to this embodiment, the polarized light separator 40 is arranged outside the glass substrate 22 constituting the STN cell 20, and the color filter 60 and the reflecting plate 50 are arranged outside the polarized light separator 40. Therefore, a so-called parallax error in which a double display is caused by the thickness of the glass substrate 22 easily occurs. For this reason, in this embodiment, the color filter 60 is caused to correspond to a display pattern, and the color filter 60 is formed to have a size slightly larger than the display pattern.

Although a polychromatic display of a plurality of colors is obtained on a screen, the same color is always displayed on the same display pattern.

This phenomenon will be further described below with reference to Figs. 6 to 8.

As shown in Fig. 6, in the icon portion 240, the color filters 641 to 643 are arranged in correspondence with the three icons 241 to 243 However the sizes of the color filters 641 to 643 are set to be slightly larger than those of the icons 241 to 243, respectively. Intervals are formed between the color filters 641 to 643. In this manner, color displays in units of icons 241 to 243 can be obtained, and the icons 241 to 243 always displays the same colors, respectively. Even if a small parallax error occurs, the parallax error is negligible as far as the displays of the icons 241 to 243 are seen.

As shown in Fig. 7, the dot portion 210 comprises the dot row display portions 220 and 230 constituting two rows. However, the color filters 620 and 630 are arranged for the two dot row display portions 220 and 230, respectively, the color filter 620 is formed to have a size slightly larger than the dot display portions 221 to 224 constituting the dot row display portion 220, and the color filter 630 is formed to have a size slightly larger than the dot display portions 231 to 234 constituting the dot row display portion 230. An interval is formed between the color filter 620 and 630. In this manner, displays in units of dot row display portion 220 and 230, and the dot row display portions 220 and 230 always display the same displays the same colors, respectively. Even if a small parallax error occurs, the parallax error is negligible as far as the displays of the dot row display portions 220 and 230 in units of rows are seen.

As described above, in this embodiment, color filters are arranged in units of rows. However, color filters may be arranged in units of columns to obtain color displays in units of columns.

As shown in Fig. 8, color filters 621 to 624 and 631

to 634 are arranged in correspondence with the dot display portions 221 to 224 and 231 to 234, and the color filters 621 to 624 and 631 to 634 are formed to have sizes slightly larger than those of the dot display portions 221 to 224 and 231 to 234, and intervals can be formed between the color filters 621 to 624 and 631 to 634.

In this manner, displays in units of the dot display portions 221 to 224 and 231 to 234, i.e., a display in unit of one character or one symbol, is obtained, and the unit of one character or one symbol always displays the same color. For this reason, even if a small parallax error occurs, the parallax error is negligible as far as a display in unit of one character or one symbol is seen.

Fig. 9 is a view for explaining a liquid-crystal display device according to the fourth embodiment of the present invention, in which Fig. 9A is a plan view, and Fig. 9B is an exploded sectional view.

In the third embodiment, aluminium, silver, or the like is deposited on the substrate 52 to form the reflecting plate 50, and the color filter 60 is printed on the reflecting plate 50. In contrast to this, the fourth embodiment is the same as the first embodiment except that a color filter 60 is printed on the upper surface of a substrate 56 constituted by a glass substrate or a PET substrate, and aluminium or the like is deposited on the lower surface of the substrate 56 to form a reflecting layer.

Fig. 10 is a view for explaining a liquid-crystal display device according to the fifth embodiment of the present invention, in which Fig. 10A is a plan view, and Fig. 10B is an exploded, sectional view.

In the third embodiment, a color filter 60 is printed on a reflecting plate 50. In contrast to this, the fifth embodiment is the same as the first embodiment except that a color filter 60 is printed on the lower surface of a polarized light separator serving as a polarized light separator 40 and disclosed in International Unexamined Publication WO95/17692.

Fig. 11 is a view for explaining a liquid-crystal display device according to the sixth embodiment of the present invention, in which Fig. 11A is a plan view, and Fig. 11B is an exploded sectional view.

In the third embodiment, the color filter 60 is printed on the reflecting plate 50. In contrast to this, the sixth embodiment is the same as the first embodiment except that a fluorescent coating 62 is formed on the reflecting plate 50 in place of the color filter 60. Although the fluorescent coating 62 is properly selected to perform a color display of a plurality of colors, the same color is always displayed on the same display pattern. Fig. 12 is a view for explaining a liquid-crystal display device according to the seventh embodiment of the present invention, in which Fig. 12A is a plan view, and Fig. 12B is an exploded sectional view.

In the third embodiment, aluminium or silver is deposited on the substrate 52 to form the reflecting plate 50, and the color filter 60 is printed on the reflecting plate 50. In contrast to this, the seventh embodiment is the same as the first embodiment except that a film 70 consisting of PET or the like is selectively colored in a plurality of colors to form a color filter 76, and a deposition film 74 consisting of aluminium or the like is formed on the lower surface of the film 70 to form a reflecting layer.

Fig. 13 is a view for explaining a liquid-crystal display device according to an eighth embodiment of the present invention, in which Fig. 13A is a plan view, and Fig. 13B is an exploded sectional view. Figs. 14 and 15 are plan views for explaining the liquid-crystal display device according to the eighth embodiment;

In the third embodiment, aluminium or silver is deposited on the substrate 52 to form the reflecting plate 50, and the color. filter 60 is printed on the reflecting plate 50. In contrast to this, the eighth embodiment is the same as the first embodiment except that a hologram 80 in which a color generation area 82 for generating different colors is selectively arranged is arranged between a polarized light separator 40 and a reflecting plate 50.

In this embodiment, although color generation of the color generation area 82 is properly selected to perform a color display of a plurality of colors, the same color is always displayed on the same display pattern. For example, as shown in Fig. 14, only areas corresponding to icons may be constituted by color generation areas 802, 804, and 806 which have colors different from each other, and the remaining area may be constituted by a color generation area 84 having the same color. As shown in Fig. 15, color generation areas 812, 814, 816, 822, 824, 826, and the like in which different colors are vertically arranged in units of dots may be arranged.

Fig. 16 is a view for explaining a liquid-crystal display device according to a ninth embodiment of the present invention, in which Fig. 16A is a plan view, Fig. 16B is an exploded sectional view, and Fig. 16C is a partially enlarged plan view.

In the third embodiment, the glass substrate 22 is used as a substrate under the STN cell 20, aluminium, silver, or the like is deposited on the substrate 52 to form the reflecting plate 50, and the color filter 60 is printed on the reflecting plate 50. In contrast to this, the ninth embodiment is the same as the first embodiment except that a plastic film 28 is used as the substrate under a STN cell 20, and a color filter 70 is formed on the lower surface of the polarized light separator 40.

In the third embodiment, since the glass substrate 22 is used as the substrate under the STN cell 20, a parallax error caused by the thickness of the glass substrate occurs. However, as in the ninth embodiment, when the plastic film 28 is used as the substrate under the STN cell 20, the thickness of the plastic film 28 can be decreased. For this reason, parallax can be almost cancelled, and a parallax error rarely occurs. As a result, as shown in Fig. 16C, color filters (710, 720, 730, and 740) having different colors in units of pixels can be arranged.

Fig. 17 shows an example of a portable telephone

set in which a display device according to the present invention is arranged. In this portable telephon set 900, a display device according to the third embodiment is used as a display portion 901.

Although the display device of the third embodiment is used, depending on the application, any one of the display devices described in the third to ninth embodiments can be used.

Although a portable telephone set is described as an example, the display device can also be used in various electronic apparatuses such as a personal computer, a car navigation system, or an electronic organizer.

In the display device according to the present invention, the following two display states can be obtained. That is, the first display state obtained by light reflected from a second polarized light separation means depending on the state of a transmission polarized light axis of a transmission polarized light axis changing means, and the second display state obtained by light which is emitted from an optical element, is in a predetermined wavelength area, and is transmitted through the second polarized light separation means. Since the first display state is obtained by light reflected by the second polarized light separation means, a display device which achieves a bright display can be obtained. As the second polarized light separation means, a polarized light separation means which transmits, in response to light in an almost whole wavelength range of a visible light area, a linearly polarized light component of a second predetermined direction of the light being incident from the transmission polarized light axis changing means to the optical element, reflects the linearly polarized light component of a third predetermined direction perpendicular to the second predetermined direction, and can emit the linearly polarized light of the second predetermined direction to the transmission polarized light axis changing means in response to light which is light in the almost whole wavelength range of the visible light area and is incident from the optical element is used. Therefore, the first and second display states can be obtained in response to light in the whole wavelength range of the visible light area, transparent reflection or white reflection can be obtained in the first display state, and, in the second display state, a display of an arbitrary color can be obtained in the whole wavelength range of the visible light area depending on the optical element.

Claims

1. A display device comprising:

   transmission polarisation changing means (140) for selectively changing the polarisation axis of transmitted light in response to the application of voltage;

   characterised by first (130) and second (160) polarized light separation means arranged on opposite sides of said transmission polarisation changing means; and

   optical means (170), disposed on an opposite side of said second polarized light separation means relative to said transmission polarization changing means, for emitting light, in a predetermined wavelength range, toward said second polarized light separation means in response to light from said second polarized light separation means,

   wherein said first polarized light separation means is such as to transmit light linearly polarized in a first predetermined direction in response to light incident from a first side thereof, and to transmit from the first side light linearly polarized in the first predetermined direction in response to light incident from the second side, and

   said second polarized light separation means is such as to transmit light linearly polarized in a second predetermined direction, being incident from said transmission polarisation changing means, and to transmit light incident from said optical means, and linearly polarized in the second predetermined direction to said transmission polarisation changing means, and to reflect light linearly polarized in a third predetermined direction perpendicular to the second predetermined direction back to said transmission polarisation changing means.

2. A display device according to claim 1, wherein said second polarized light separation means is operative in response to light over the wavelength range of visible light.

3. A display device according to claim 1 or 2, wherein said second polarized light separation means transmits the linearly polarized light towards said optical means as linearly polarized light in the second predetermined direction.

4. A display device according to any preceding claim, wherein said second polarized light separation means comprises a (1/4) λ plate (162), and a liquid crystal layer (164), preferably cholesteric.

5. A display device according to any of claims 1 to 3, wherein said second polarized light separation means comprises a multilayered structure (190) formed by a stack of a plurality of layers, in which adjacent layers (191, 192) have refractive indexes which are equal to each other in the second predetermined direction ($n_a y$, $a_b y$) and are different from each other ($n_a x$, $n_b x$) in the third direction.

6. A display device according to claim 5, wherein the

thickness of adjacent layers t_a, t_b is given by $t_a n_{ax} + t_b n_{bx} = \lambda/2$.

7. A display device according to any preceding claim, wherein said transmission polarisation changing means is a liquid-crystal element.

8. A display device according to any preceding claim, wherein said optical means absorbs light in a wavelength area other than the predetermined wavelength range of the light from said second polarized light separation means, reflects the light in the predetermined wavelength range toward said second polarized light separation means, and can transmit the light in the predetermined wavelength area.

9. A display device according to any preceding claim, including a reflector means (180) arranged on a side opposite said second polarized light separation means with respect to said optical means for reflecting at least the light in the predetermined wavelength area.

10. A display device according to any preceding claim, further comprising a second optical means (620-643) being capable of reflecting light in a second predetermined wavelength area different from the first predetermined wavelength area back towards said second polarized light separation means whereby a display by at least light in the first predetermined wavelength area and light in the second predetermined wavelength area in separate spatial regions on the same screen is made possible.

11. A display device according to claim 10, wherein said first and second optical means are formed in spaced regions (62) on a substrate, preferably a reflecting plate (50).

12. A display device according to any preceding claim, wherein the first mentioned or second optical means is a hologram (80) which can color the light in the second predetermined wavelength area by the light from said second polarized light separation means.

13. A display device according to any preceding claim, wherein at least one of the optical means includes a color filter.

14. A display device according to any preceding claim, wherein at least one of the optical means includes dots preferably of phosphor.

15. A display device according to preceding claim, further comprising first and second glass transparent substrates (21, 22) arranged on both sides of said transmission polarized light axis changing means to sandwich said transmission polarized light axis changing means,

and wherein said optical means are made larger than necessary to reduce parallax effects.

16. A display device according to any preceding claim, further comprising first and second transparent substrates (21, 22) arranged both the sides of said transmission polarized light axis changing means to sandwich said transmission polarized light axis changing means.

17. A display device according to claim 20, wherein a polychromatic display (210-240) is performed in units of rows or characters in an icon portion or dots.

Fig. 1

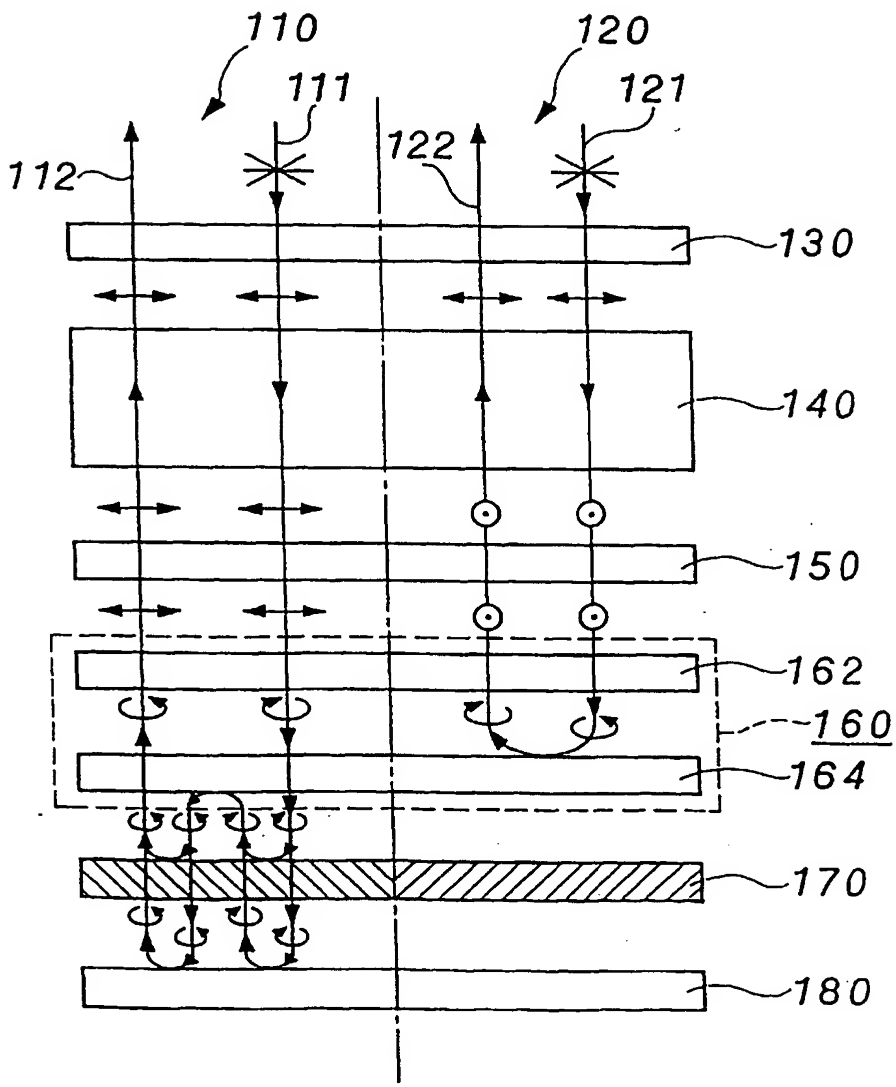

Fig. 2

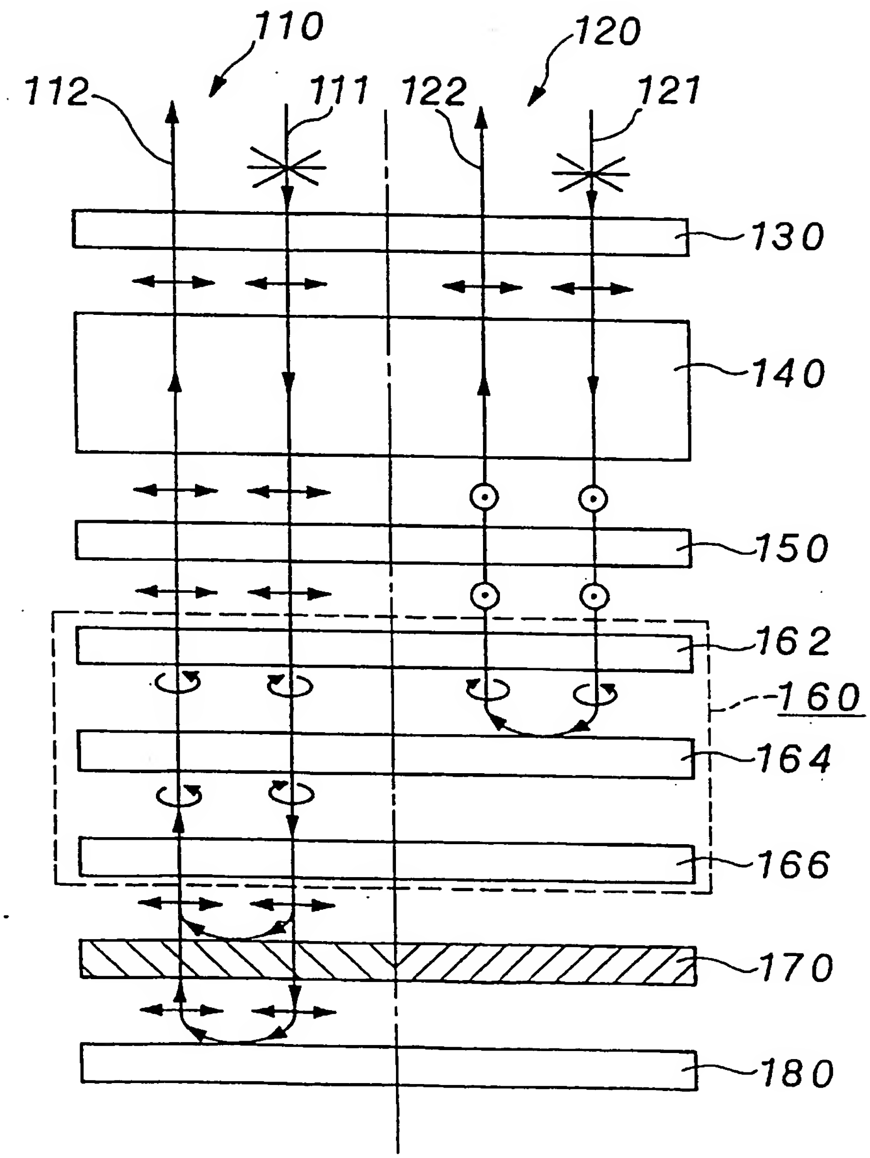

Fig. 3

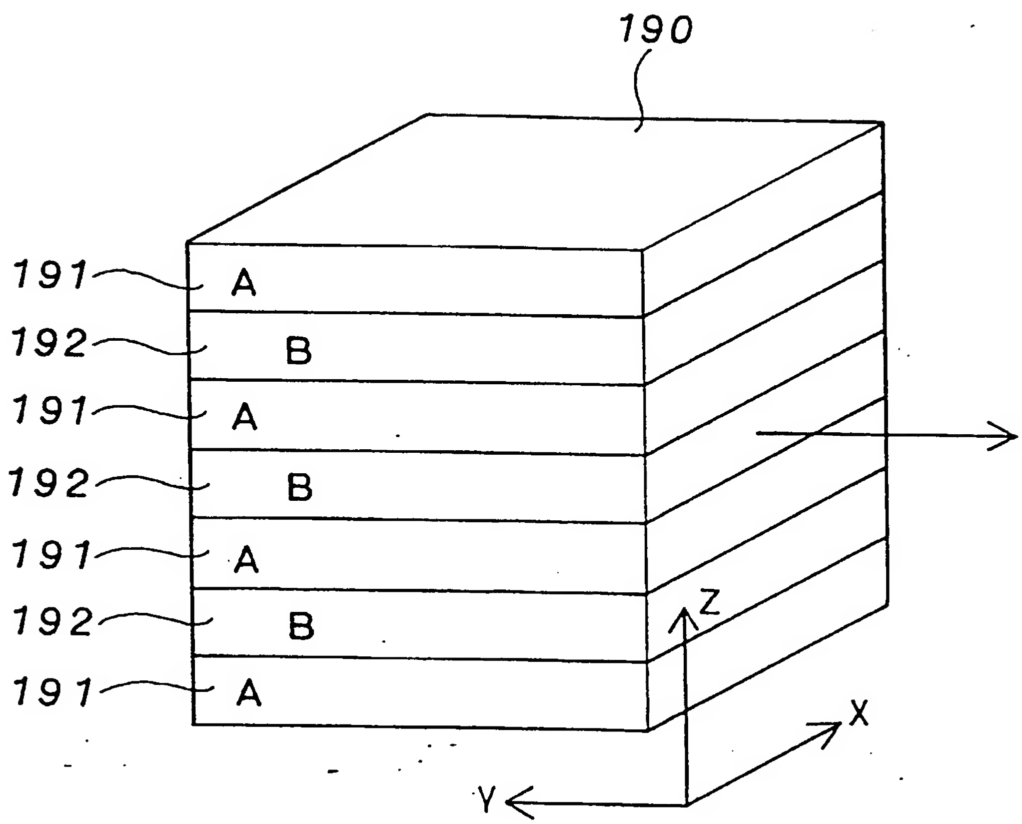

Fig. 4

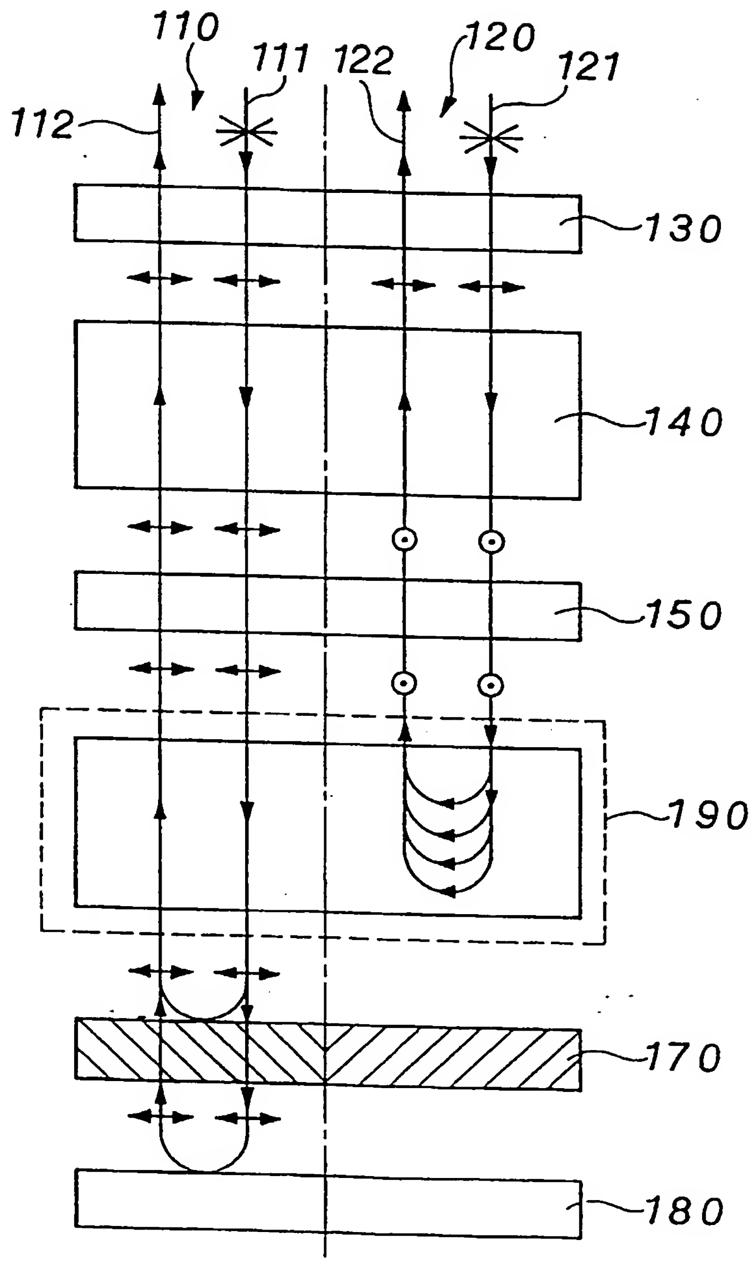

Fig. 5

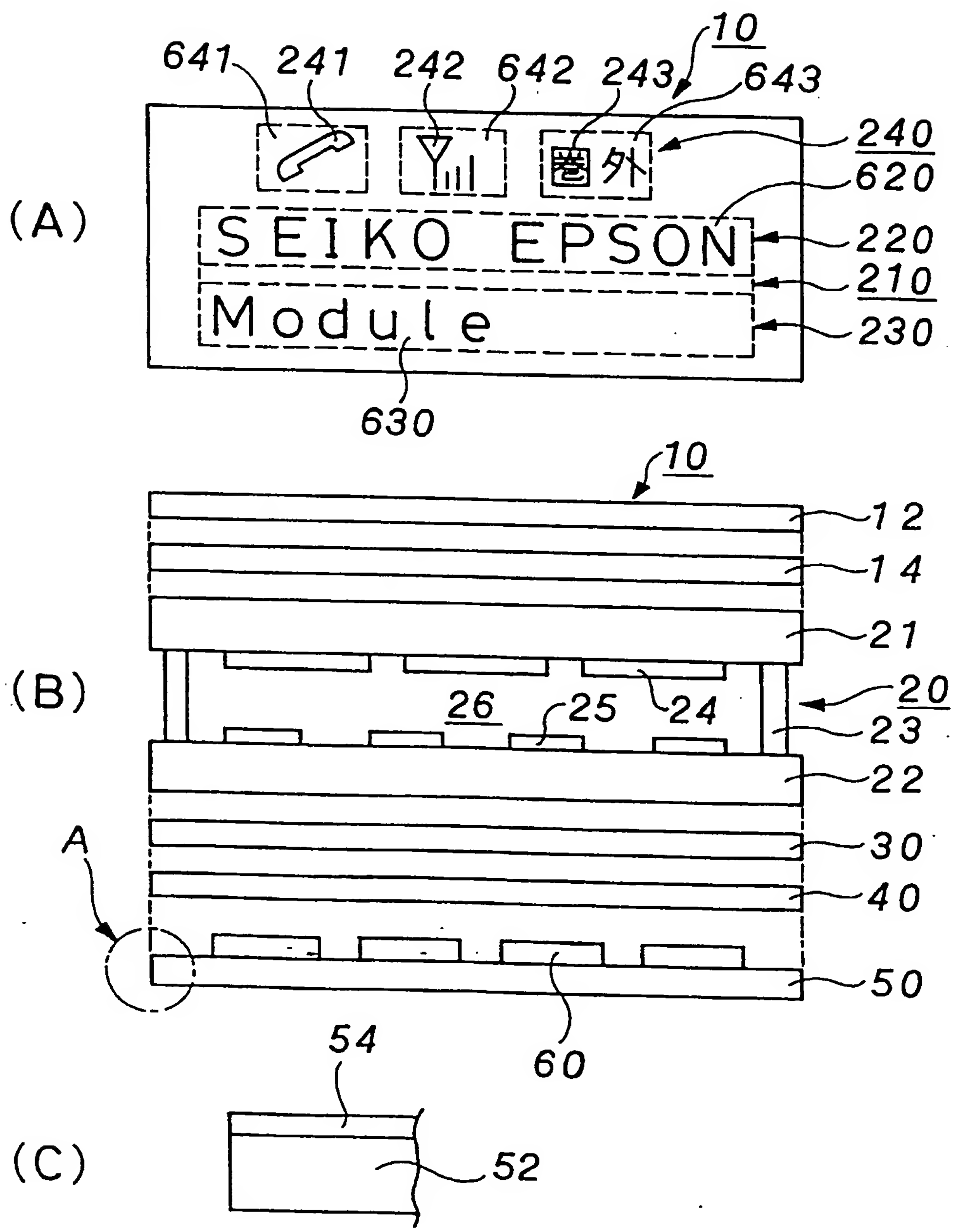
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Fig. 6

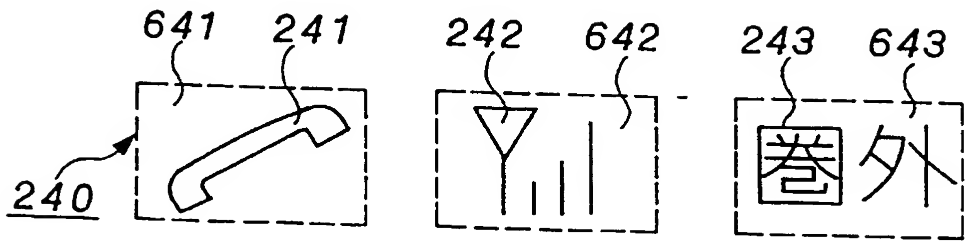
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Fig. 7

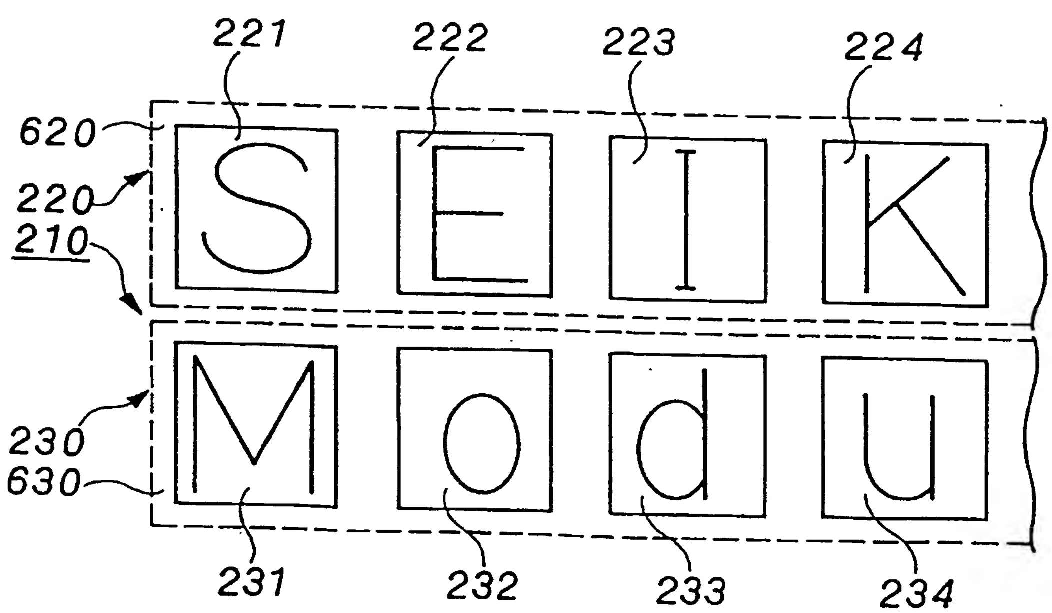
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Fig. 8

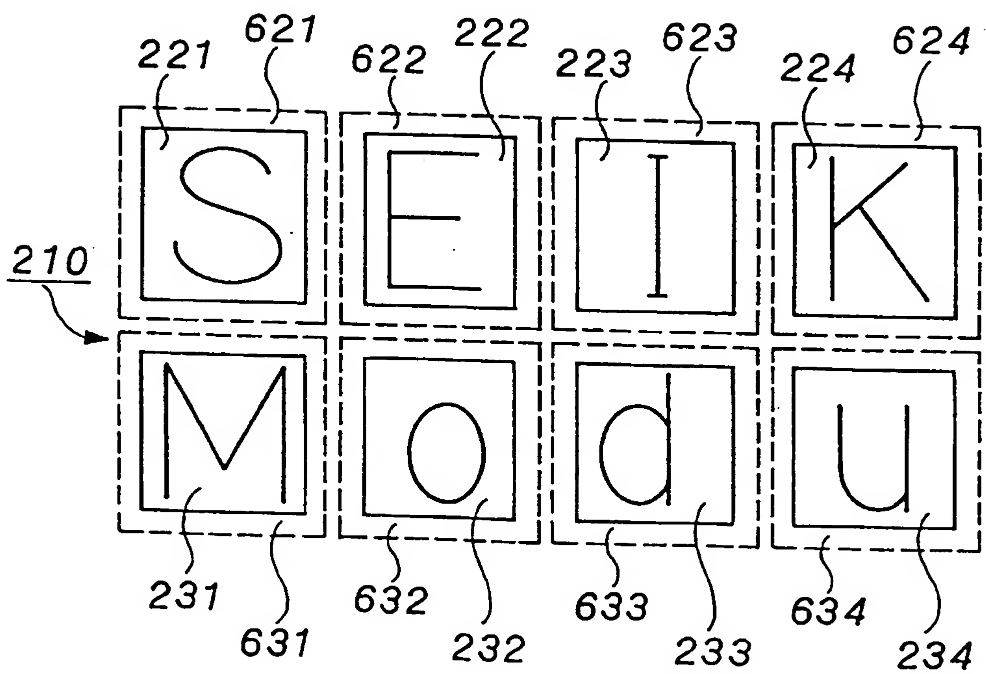
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Fig. 9

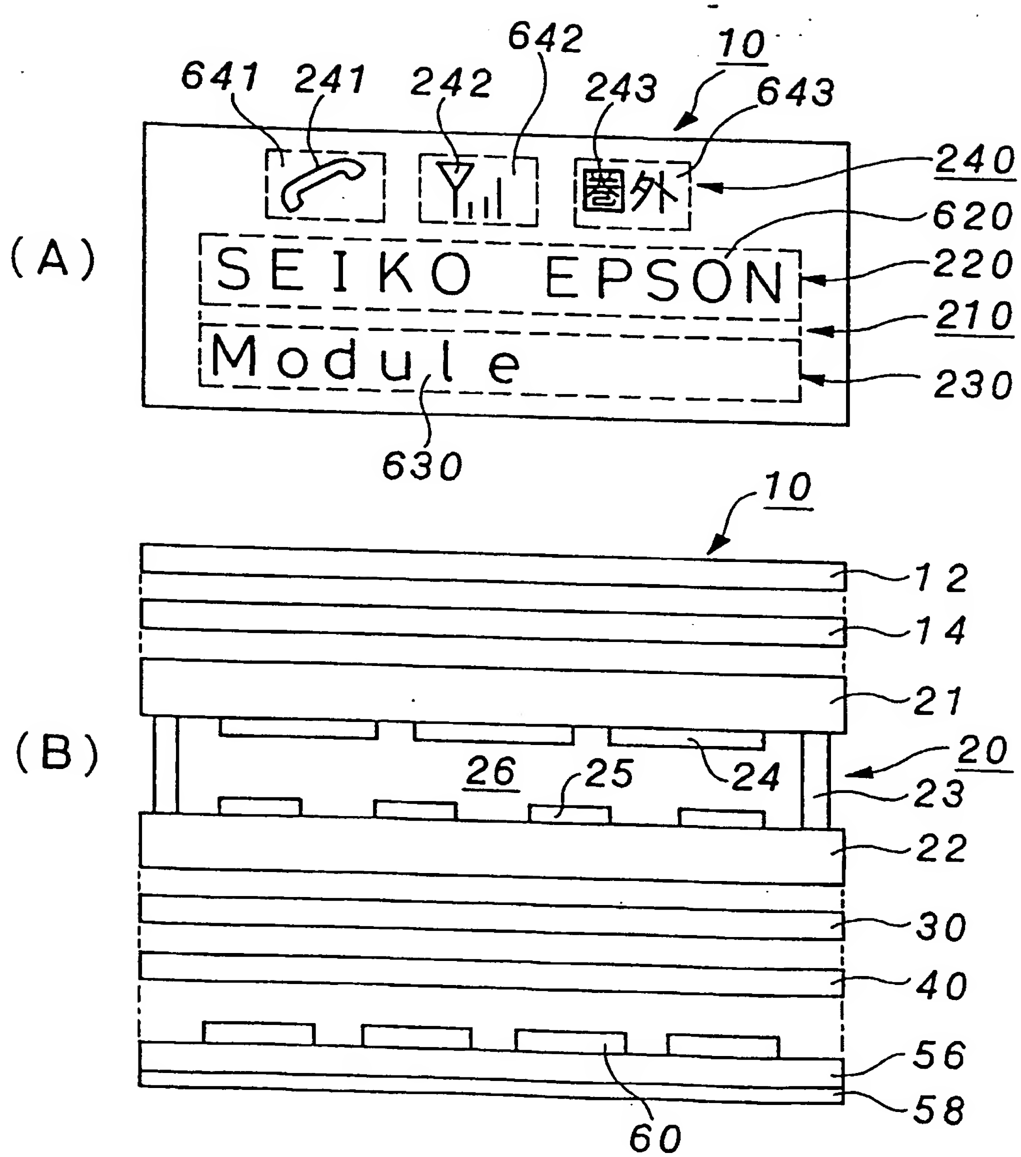
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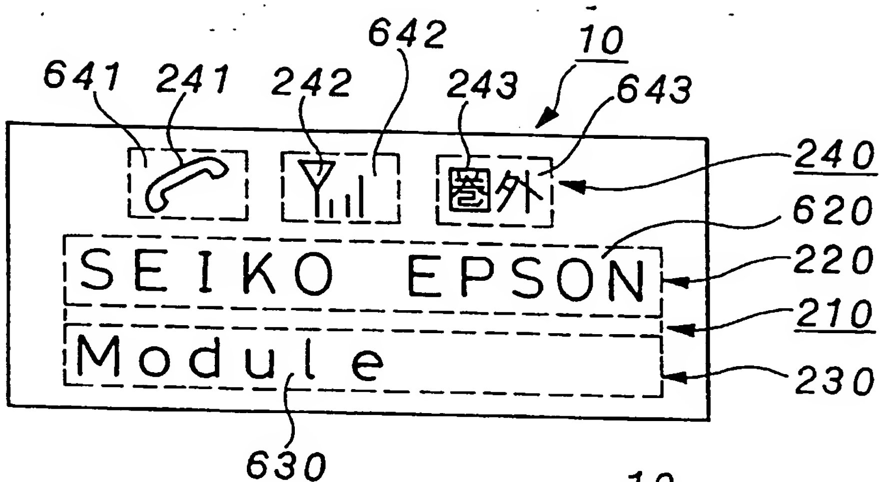
Fig. 10

(A)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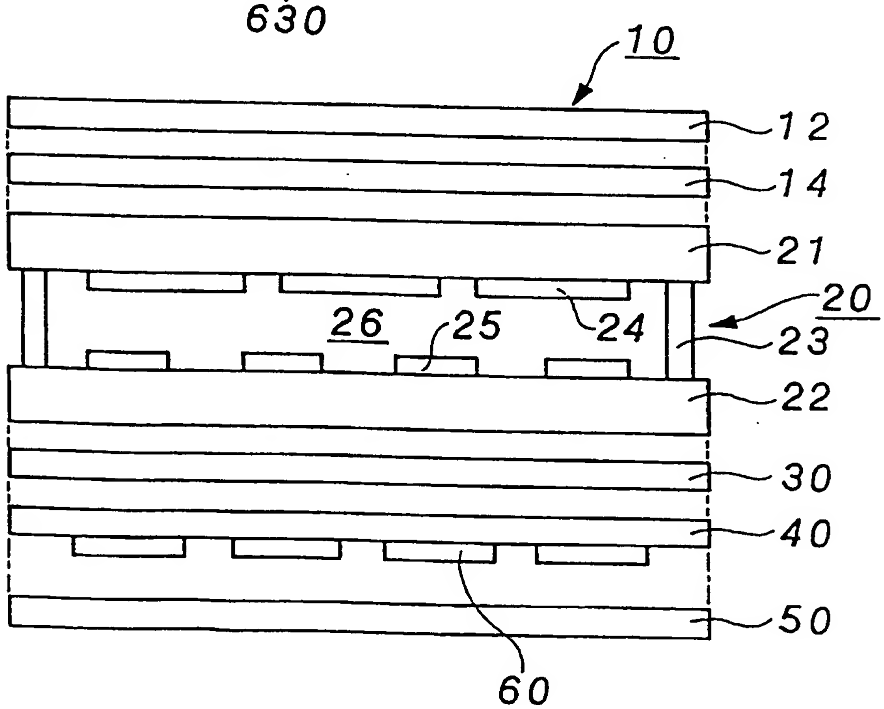
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Fig. 11

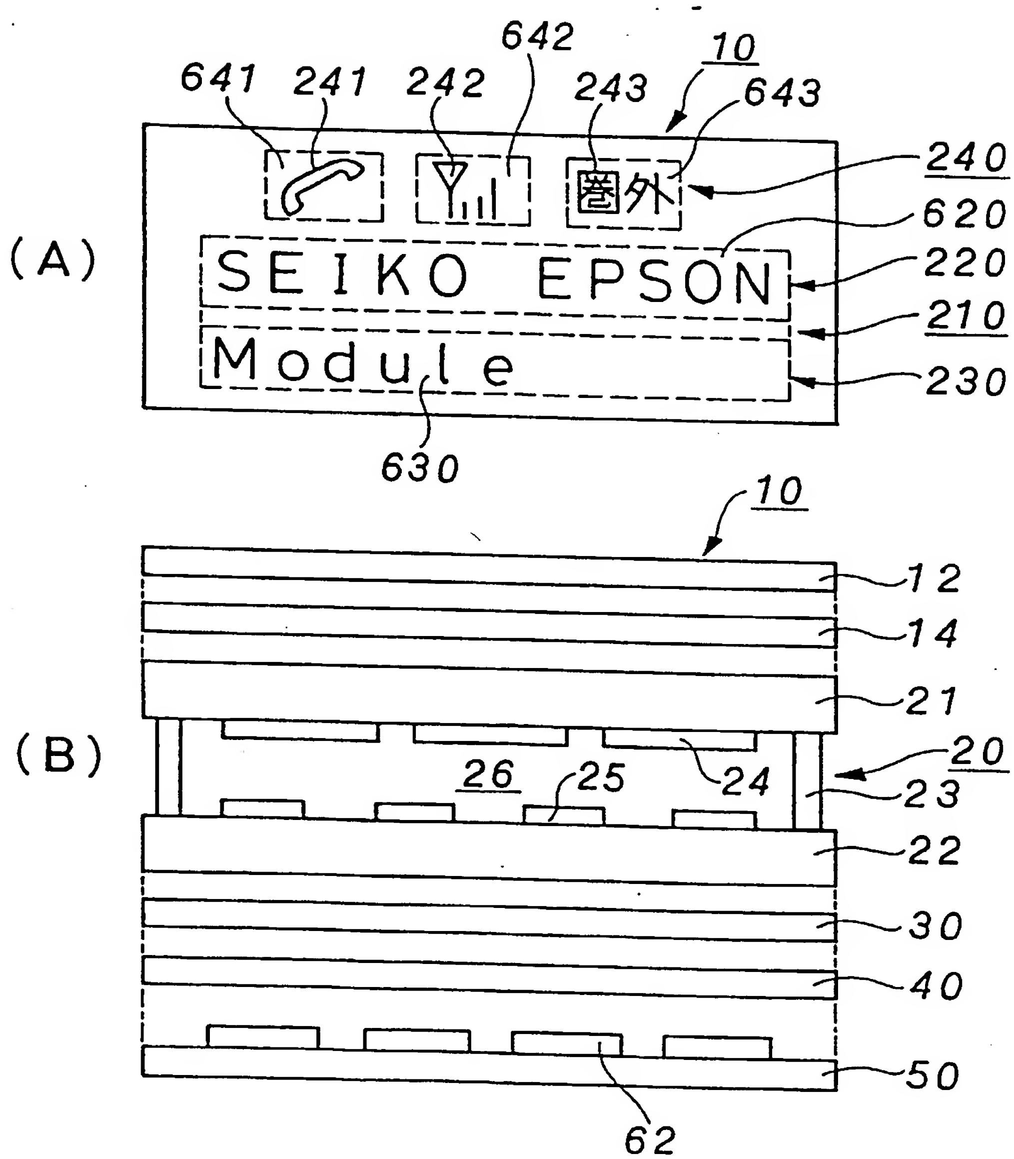

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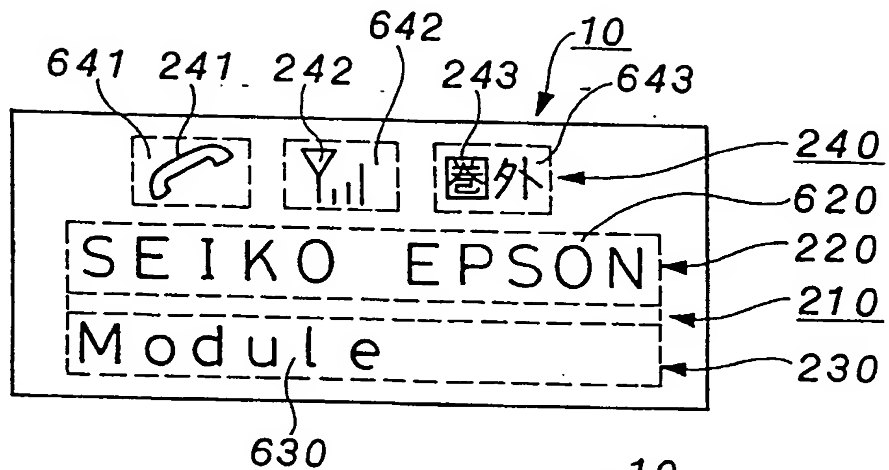
Fig. 12

(A)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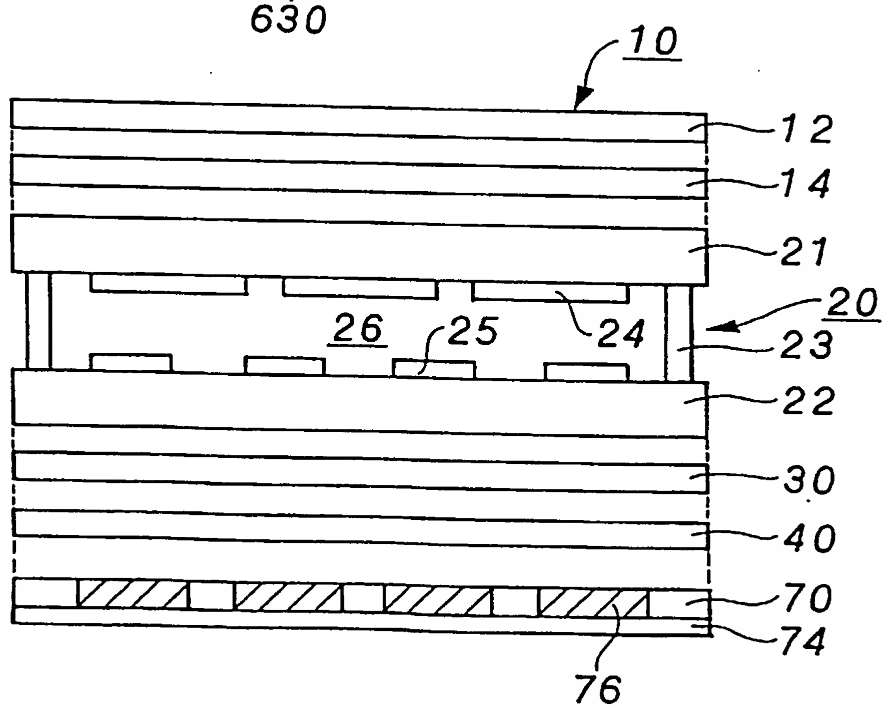
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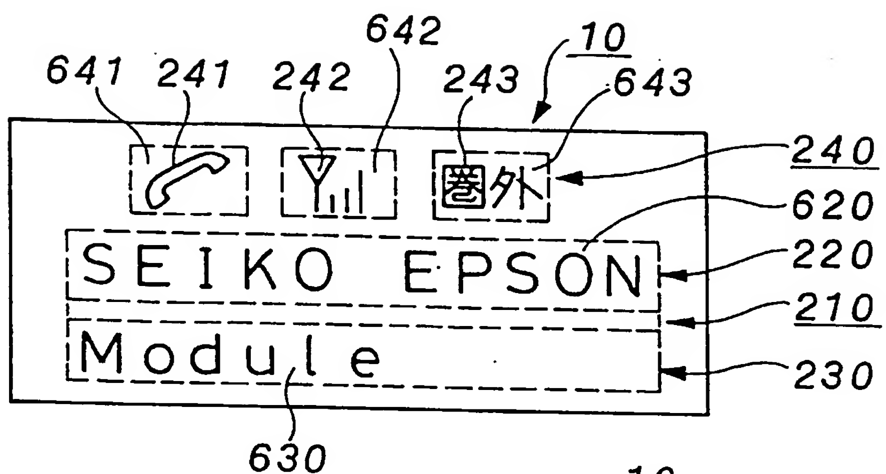
Fig. 13

(A)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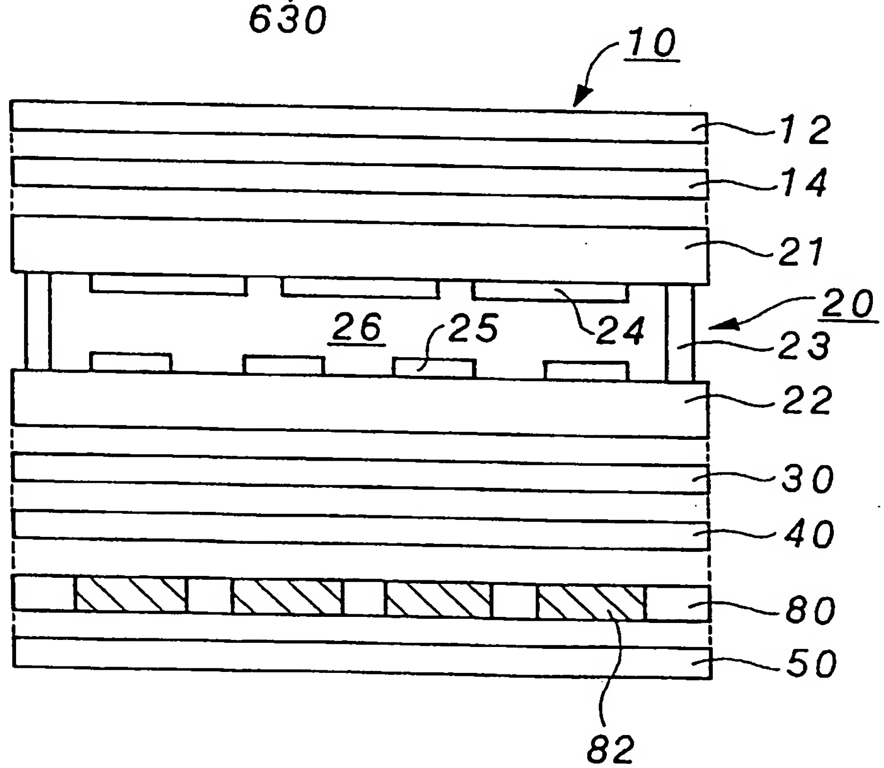
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Fig. 14

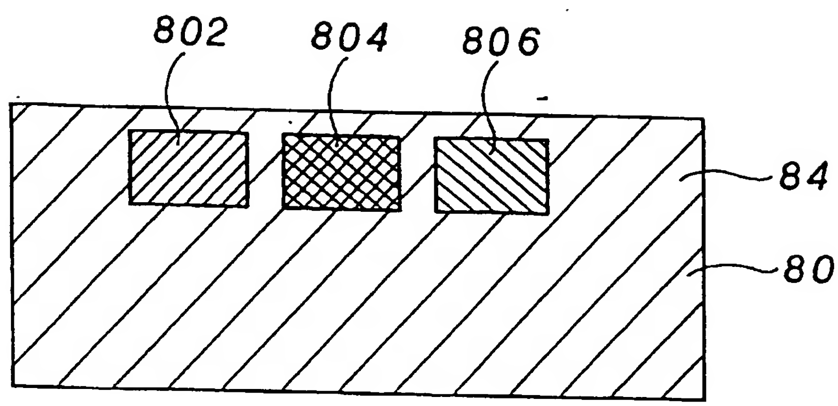


Fig. 15

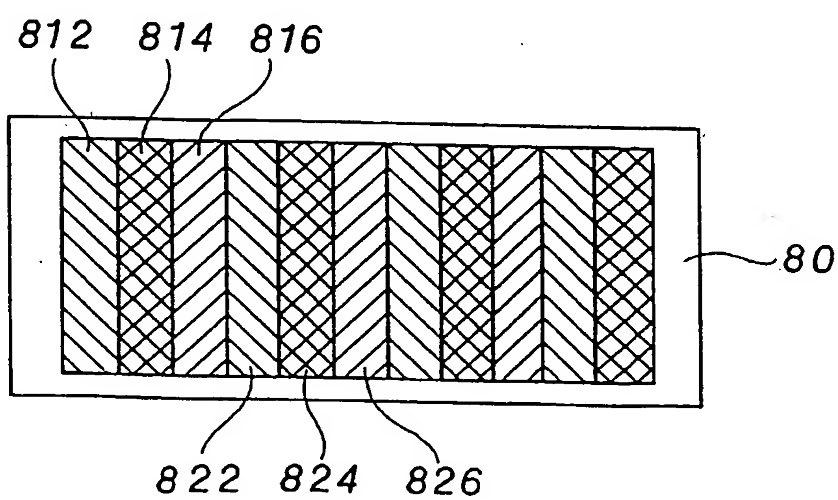
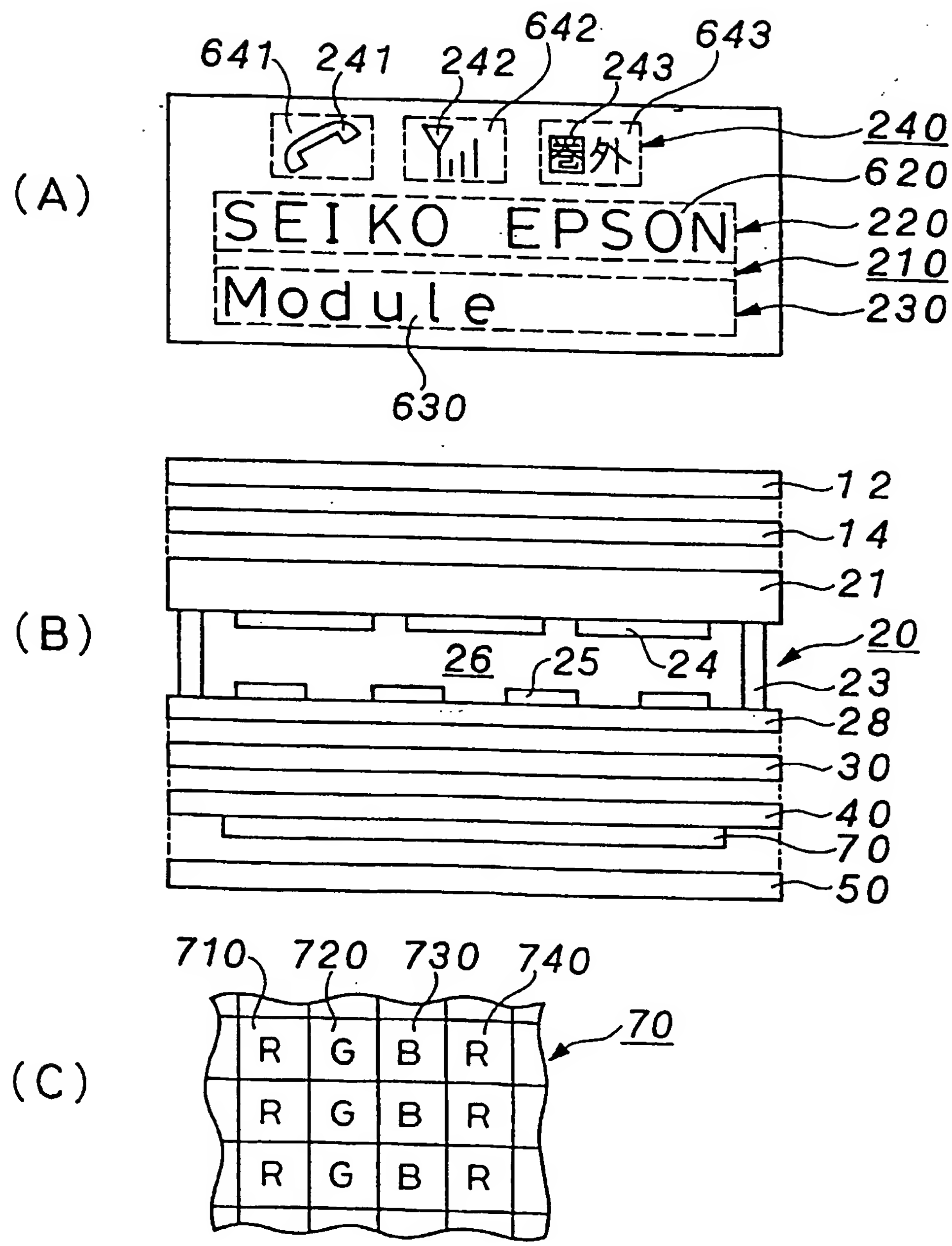


Fig. 16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242
642
243
643
圏外
240
620
SEIKO EPSON
220
210
Module
230
630
(B)
12
14
21
20
26
25
24
23
28
30
40
70
50
(C)
710
720
730
740
70
R G B R
R G B R
R G B R

Fig. 17